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Reevaluation of health risk benchmark for sustainable water practice through risk analysis of rooftop-harvested rainwater

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ABSTRACT

Health risk concerns associated with household use of rooftop-harvested rainwater (HRW) constitute one of the main impediments to exploit the benefits of rainwater harvesting in the United States. However, the benchmark based on the U.S. EPA acceptable annual infection risk level of $\leq$1 case per 10,000 persons per year ($\leq 10^{-4}$ pppy) developed to aid drinking water regulations may be unnecessarily stringent for sustainable water practice. In this study, we challenge the current risk benchmark by quantifying the potential microbial risk associated with consumption of HRW-irrigated home produce and comparing it against the current risk benchmark. Microbial pathogen data for HRW and exposure rates reported in literature are applied to assess the potential microbial risk posed to household consumers of their homegrown produce. A Quantitative Microbial Risk Assessment (QMRA) model based on worst-case scenario (e.g. overhead irrigation, no pathogen inactivation) is applied to three crops that are most popular among home gardeners (lettuce, cucumbers, and tomatoes) and commonly consumed raw. The infection risks of household consumers attributed to consumption of these home produce vary with the type of produce. The lettuce presents the highest risk, which is followed by tomato and cucumber, respectively. Results show that the 95th percentile values of infection risk per intake event of home produce are one to three orders of magnitude (10^{-7} to 10^{-5}) lower than U.S. EPA risk benchmark ($\leq 10^{-4}$ pppy). However, annual infection risks under the same scenario (multiple intake events in a year) are very likely to exceed the risk benchmark by one order of magnitude in some cases. Estimated 95th percentile values of the annual risk are in the 10^{-4} to 10^{-3} pppy range, which are still lower than the 10^{-3} to 10^{-1} pppy risk range of reclaimed water irrigated produce estimated in comparable studies. We further discuss the desirability of HRW for irrigating home produce based on the relative risk of HRW to reclaimed wastewater for irrigation of food crops. The appropriateness of the $\leq 10^{-4}$ pppy risk benchmark for assessing safety level of HRW-irrigated fresh produce is questioned by considering the assumptions made for the QMRA model. Consequently, the need of an updated approach to assess appropriateness of sustainable water practice for making guidelines and policies is proposed.

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1. Introduction

Increasing scarcity of readily available water and energy resources, population growth, aging water infrastructures, and extreme weather phenomena have presented daunting challenges to global water securities in recent years (Grant et al., 2012; Vorosmarty et al., 2010). Sustainable water resource management, such as wide-scale adoption of low-impact development (LID) and green infrastructures, could be one of the key solutions to alleviate these heavy burdens (Roy et al., 2008). LIDs, for example, rain gardens, vegetated rooftops, permeable pavements, and rainwater tanks, are decentralized, onsite stormwater management tools which can be applied to both existing developments and new ones for preserving and/or restoring pre-development hydrological features and reducing pollution loads to aquatic environments. In other cases, the collection of rainwater using LIDs as an additional water resource has been a partial solution to alleviate water supply burdens in arid countries like Jordan and Tunisia (Abu-Zreig et al. 2013). Harvesting rainwater from rooftops to supplement household or local water needs represents one of the simplest, yet effective LIDs that define sustainable practice suitably. Here, a distinction is made between harvested rainwater (HRW) and stormwater. HRW is rainwater that falls onto rooftop of buildings and is collected directly into a rain storage tank. Stormwater, on the other hand, is rainwater that falls onto catchment areas such as roads and pavements, and therefore collects many more pollutants before discharge into any stream or stormwater collection system. Extensive use of HRW as alternative water supplies is not only limited to arid countries, but has been a common trend in cities of many developed countries such as Australia, Germany, and Japan. For example, many urban regions in Australia harvest rainwater from rooftop for both potable (less common) and non-potable purposes (Sinclair et al., 2005).

However, adoption and scale of rainwater harvesting practice vary from place to place, and are dependent on the awareness of the public as well as legislative, financial, and technical support programs towards the practice (Abu-Zreig et al., 2013; Ward et al., 2013). Ward et al. (2013) studied the water-user perceptions towards rainwater harvesting in UK, where water users expressed an overall positive receptivity of using HRW for a wide range of uses (but less positive receptivity towards water use of more personal contact). They concluded that the receptivity of water users towards HRW in developed countries is high in places with persistent water issues (e.g. limited water resources), where water reuse is becoming an accepted and normal part of everyday life.

In the United States, health risks associated with using HRW represent one of the greatest concerns for the public, who have accustomed to using potable water for every end-use and deemed any lesser quality water unsafe. Skeptical city officials who adopt rainwater tanks do not recommend the use of stored rainwater for household purposes, opting to discharge them after storm events as a mean to manage/reduce stormwater pollution (City of Los Angeles, 2011). Lack of governmental guidelines for safe usage of HRW is a main contributing factor for varying perspectives across different agencies in the nation regarding the best practice to utilize their stored rainwater (Kloss, 2008). As of the end of 2012, only 12 out of 50 states in the U.S. have their own rainwater-harvesting laws (National Conference of State Legislature, 2013) that deal with different aspects of the practice (encouraging or prohibiting the practice, and/or restrict HRW usage options, etc). More recently, there are also a number of local governments in the cities of Atlanta, Portland, and Cincinnati who changed their local codes to allow for rainwater uses. These changes were met by resistance from government-run drinking water providers in fear that wide-scale adoption of rainwater harvesting practice will result in community revenue loss on their part. This trend shows the diverse opinions at both state and local level regarding rainwater harvesting and also the lack of scientific studies to support the practice (Roy et al. 2008).

It is apparent that the current water policy or lack of an adequate water policy in the U.S. has obstructed the progress of sustainable water practices. Transition of water management have been slow due to the lack of support for adopting new standards that conflict against existing (but often outdated) standards, which were established decades ago. Sustainable water practices such as application of HRW for various end-uses often find themselves disadvantaged to be benchmarked against stringent standards such as the safe drinking water standards. The science behind the establishment of the latter was based on risk assessment paradigms, but this risk-based approach has seldom been applied to other sustainable water practices for non-potable uses in the U.S. It is therefore proposed to guide sustainable water practices using the same strategy, where risk assessment serves as the main tool to answer the appropriateness of each practice (Fewtrell and Kay, 2007).

Putting this into context, urban agriculture in densely populated cities such as New York City is rapidly growing due to the adoption of LIDs to manage stormwater, and the recognition of the long forgotten idea of using HRW for irrigating crops (Design Trust for Public Space, 2013). However, most HRW quality reported in literature did not comply with the U.S. EPA safe drinking water standards (Abbasi and Abbasi, 2011). HRW collects chemical pollutants from dry deposits, microbial pathogens from feces of birds, rats and other wild animals resting/nesting on the rooftops (Simmons et al. 2001). These pathogens washed into the storage tank by rain could survive in the tank and potentially transmitted to the HRW end-users. Thus, using HRW for irrigating crops could result in (chemical and microbial) contamination of the crops. Epidemiological data have indicated that foodborne disease outbreaks are most prominent where there are continuing sources of infection, for example, serving of contaminated food in restaurants (Todd et al., 2007). If restaurants in New York City decided to use their city-grown HRW-irrigated crops for preparation of raw salads, there exist risks of foodborne disease outbreak. Nevertheless, in a comparative analysis, prior to the rise of urban agriculture in New York City, people may be eating raw vegetables irrigated with secondary-treated effluents imported from countries with uncertain sanitary practices (Beuchat, 2002). Such dichotomy argues for reevaluation of heath risk benchmark for sustainable water practice.

Here, we attempt to assess the appropriateness of using untreated HRW to water lawns and/or gardens, which is